

3.3. Health risk assessment

As noted at the onset, health risk assessments for naphthalene are in flux. The current reference concentration (RfC) of $3 \mu\text{g m}^{-3}$ established by US EPA [17] represents a threshold effects level. Five studies have reported higher average indoor concentrations: one study of mostly smoking homes [104]; one including homes receiving occupant complaints [105]; and three more representative studies [107,113,115]. None of the outdoor studies and none of the median concentrations in the indoor studies exceeded the RfC.

The estimated cancer risks from naphthalene exposure are notable. The 2002 National-Scale Assessment concluded that naphthalene in ambient air was a regional cancer risk “driver”, defined as an air toxic where the typical individual chronic cancer risk exceeded 10^{-5} [21]. Naphthalene was ranked the second highest indoor risk driver and the third highest outdoor risk driver in a Michigan study [107]. Loh *et al.* [36] derived personal exposures using a microenvironmental model, and ranked naphthalene as ninth among 19 carcinogenic air pollutants. Using the draft URE [18], cancer risks will increase 3-fold and typical risk levels will approach or fall into the 10^{-4} range, while peak measurements, if reflective of chronic exposure, represent cancer risks in the 10^{-3} or possibly even higher range. If the tumor response in experimental animals is confirmed to be predictive of human health risk, these risks will be significant, especially given the millions of individuals exposed.

The true cancer risk due to naphthalene exposure remains controversial. Much of the debate focuses on site concordance, that is, whether carcinogenic effects seen in experimental animals [3] can be extrapolated to humans. Both U.S. EPA [18] and IARC [14] judge that epidemiological data are inadequate for determining human carcinogenicity. In a screening level assessment, the predicted number of naphthalene-induced nasal tumor cases in the U.S. using the draft EPA unit risk factor (URFs) was 65,905, far exceeding the 910 observed [23]. Clearly,

the URFs derived from animal data have large uncertainties.

[Go to:](#)

4. Discussion

Naphthalene is one of the least volatile VOCs and the most volatile PAH. Because this compound has often been excluded in both VOC and PAH studies, the exposure-relevant literature is, in many ways, deficient and inferior to the VOC and PAH literature. Still, we identified 20 recent indoor studies and 21 recent outdoor studies, which were used to derive representative ranges of concentrations applicable to residences and urban settings. Only three studies making personal measurements in community settings were identified, all in Europe.

4.1. Information gaps

We note a number of important information gaps. For indoor settings, the available studies are suggestive but inconsistent with respect to the influence of potential naphthalene sources, such as moth repellents, air fresheners, and deodorizers. There is little if any quantification of these sources. In the outdoor studies, information regarding emission inventories, long range transport, source apportionments and long-term trends is incomplete, certainly as compared to other VOCs and PAHs [148]. Large gaps exist regarding the availability of information on personal exposures, and no North American studies were identified. This is an important gap since personal exposure measurements are considered the best estimate of true exposures [149] and since U.S. and Canadian homes tended to have higher indoor concentrations than European homes. We did note that sample sizes were often limited. Finally, the suggested representative ranges for outdoor, indoor and personal measurements are rather large. We have limited confidence in the upper range of concentration measurements, e.g., our recent work has shown several homes in Detroit with naphthalene concentrations far above any listed in Table 4 (unpublished data).

Comparisons among different studies are complicated by

sampling issues (discussed below) and different siting criteria used in the various studies. Clearly, it is important to differentiate studies using monitoring sites designed to reflect urban population exposure from those designed to capture “hotspots” due to industry or traffic, as well as studies intended to characterize “background” and “remote” conditions.

4.2. Measurement issues

Naphthalene has not been included in many VOC studies, in part due to limitations of the sampling techniques. Whole-air canister sampling (TO-15), a standard U.S. EPA method [150], does not include naphthalene as a target compound, and canister methods for this compound have not been validated. Thus, ambient concentrations of naphthalene are not monitored in the nationwide Urban Air Toxics Monitoring Program. The standard adsorbent-based methods (TO-17), using either active (pumped) or passive (diffusion) sampling [151], also do not specify naphthalene as a target compound. While used, the method has been only partially validated [152]. Two popular and commercially available passive adsorbent samplers, OVM and Radiello, were not intended for naphthalene in their initial design [153,154].

None of the studies reviewed had much if any discussion of data quality issues, e.g., blank contamination, reproducibility and detection limits. Our evaluations using Tenax GR and Carbosieve adsorbents, short-path thermal desorption, and GC/MS analysis show reasonable performance can be obtained using adsorbent-based methods, although the recovery, reproducibility and other performance indicators for naphthalene are often inferior to that for other VOCs [155].

In outdoor air, vapor phase PAHs are frequently collected using high volume methods, typically with polyurethane foam (PUF) adsorbents and flow rates of 255 L min⁻¹ (TO-13A) [156]. This method was not recommended for naphthalene due to low recovery efficiency, low storage capability [156] and high breakthrough [156,157]. Because naphthalene is typically present

at concentrations that are one to two orders of magnitude higher than other PAHs, it is sometimes excluded from chemical and data analyses. Price and Jayjock [5] have suggested that naphthalene seems to be included either as a VOC or PAH for sake of completeness but that the collected data were not thoroughly analyzed.

We did not locate published reports that systematically documented laboratory or field inter-comparisons between canister or adsorbent-based sampling for VOCs, and PUF sampling for PAHs. A recent case study shows that EPA TO-15 generally yields higher concentrations for vapor phase naphthalene than EPA TO-13A [158]. In indoor applications, we have shown reasonable agreement (within factor of two) between VOC sampling using passive methods and Tenax GR adsorbents and active medium flow PUF sampling (unpublished data). However, comprehensive and robust performance evaluations are needed. While consistent and low MDLs are ideal for exposure assessment [159], the various measurement techniques attain very different MDLs, e.g., standard VOC measurements attain MDLs of about $0.01 \mu\text{g m}^{-3}$ [160], while PUF methods can go orders of magnitude lower.

[Go to:](#)

5. Conclusion

Concern regarding human exposure to naphthalene through inhalation has greatly increased due to its potential carcinogenicity, which was discovered in 2000 [3]. We derived representative ranges of residential, outdoor and personal concentrations of naphthalene, emphasizing the more recent literature. This literature is limited, especially for personal exposures. Considering what is available, we conclude that personal and residential concentrations are similar, while ambient concentrations are about an order of magnitude lower. Our estimate of representative ranges of indoor concentrations are about 0.2 to $2 \mu\text{g m}^{-3}$ for medians, and about twice that for averages.

We did not observe a decline in indoor concentrations over the

past 10 to 15 years, in contrast to trends seen for other VOCs and PAHs, however, outdoor measurements did appear to decline. We anticipate that decreased indoor smoking, improved emission controls on vehicles, and substitution of the naphthalene in moth and other animal repellents and deodorizers has significantly reduced exposures in the U.S. However, available data are not ideal for quantitative trend studies.

Most measurements fall below the current U.S. EPA reference concentration of $3 \mu\text{g m}^{-3}$ established for non-cancer effects, although measurements in several homes show concentrations approaching or exceeding $100 \mu\text{g m}^{-3}$. Outdoor exposures, except where there are strong industrial sources, are well below the RfC. However, using the available cancer risk factors, some of which are draft and under review, indoor and outdoor concentrations correspond to individual risks in the 10^{-5} to 10^{-3} range, very high for an environmental exposure. The cancer risk factors have large uncertainties and are controversial, but in many assessments naphthalene ranks at or near the top of those substances posing inhalation cancer risks. This analysis suggests that further study, control and abatement are warranted. We anticipate much higher exposures and risks in countries where these controls are lacking, or where other sources are present.

We noted a number of important information gaps and research needs. Existing exposure data are limited, and monitoring surveillance should be improved. There is a need to validate and intercompare VOC and PAH measurement techniques. This will also ensure the comparability of studies and reduce uncertainties. The spatial and temporal variability of concentrations near roads, industrial and other sources, is poorly characterized. Factors affecting indoor concentrations, including the causes of the highest levels, are not well understood, and populations at risk of high exposure presently cannot be identified. Better information regarding product usage patterns, emission rates of consumer products, building materials, and other sources of naphthalene is needed, as are long term

measurements. Future studies might address losses due to adsorption onto building materials, chemical reactions, and utilize multicompartment models to better understand current and estimate historical exposures.